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APPLICATION NUMBER: 10/723,010

FILING DATE: November 26, 2003

RELATED PCT APPLICATION NUMBER: PCT/US04/33217

**THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY
APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS
CONVENTION, IS US10/723,010**



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UTILITY
PATENT APPLICATION
TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

Attorney Docket No.

First Inventor

Title

Express Mail Label No.

Jonathan Sidney EDELSON

High Phase Order Motor with
Mesh Connected Windings

EU 334066361 US

U.S. PTO
112603
121510

1. <input checked="" type="checkbox"/> Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)	7. <input type="checkbox"/> CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)	
2. <input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.	8. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)	
3. <input checked="" type="checkbox"/> Specification [Total Pages 14] (preferred arrangement set forth below)	a. <input type="checkbox"/> Computer Readable Form (CRF)	
- Descriptive title of the invention	b. Specification Sequence Listing on:	
- Cross Reference to Related Applications	i. <input type="checkbox"/> CD-ROM or CD-R (2 copies); or	
- Statement Regarding Fed sponsored R & D	ii. <input type="checkbox"/> Paper	
- Reference to sequence listing, a table, or a computer program listing appendix	c. <input type="checkbox"/> Statements verifying identity of above copies	
- Background of the Invention	ACCOMPANYING APPLICATION PARTS	
- Brief Summary of the Invention	9. <input type="checkbox"/> Assignment Papers (cover sheet & document(s))	
- Brief Description of the Drawings (if filed)	10. <input type="checkbox"/> 37 CFR 3.73(b) Statement <input type="checkbox"/> Power of (when there is an assignee) <input type="checkbox"/> Attorney	
- Detailed Description	11. <input type="checkbox"/> English Translation Document (if applicable)	
- Claim(s)	12. <input type="checkbox"/> Information Disclosure Statement (IDS)/PTO-1449 <input type="checkbox"/> Copies of IDS Citations	
- Abstract of the Disclosure	13. <input type="checkbox"/> Preliminary Amendment	
4. <input checked="" type="checkbox"/> Drawing(s) (35 U.S.C. 113) [Total Sheets 6]	14. <input checked="" type="checkbox"/> Return Receipt Postcard (MPEP 503) (Should be specifically itemized)	
5. Oath or Declaration [Total Sheets 2]	15. <input type="checkbox"/> Certified Copy of Priority Document(s) (if foreign priority is claimed)	
a. <input checked="" type="checkbox"/> Newly executed (original or copy)	16. <input type="checkbox"/> Nonpublication Request under 35 U.S.C. 122 (b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.	
b. <input type="checkbox"/> Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional with Box 18 completed)	17. <input type="checkbox"/> Other:	
i. <input type="checkbox"/> DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) name in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).		
6. <input type="checkbox"/> Application Data Sheet. See 37 CFR 1.76		

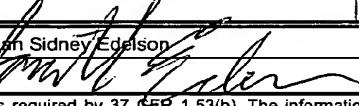
18. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:

 Continuation Divisional Continuation-in-part (CIP) of prior application No.: 09/7.13,654.....Prior application information: Examiner LE, Dang D Art Unit: 2834
For CONTINUATION OF DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference.
The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS

 Customer Number: OR Correspondence address below

Name	Borealis Technical Limited		
Address	23545 NW Skyline Blvd		
City	North Plains	State	OR
Country	US	Telephone	+1.503.621.3286
Zip Code	97133-9204		
Fax	+1.503.621.3425		

Name (Print/Type)	Jonathan Sidney Edelson	Registration No. (Attorney/Agent)	
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	Date	11/26/2003	

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FEE TRANSMITTAL

for FY 2004

Effective 10/01/2003. Patent fees are subject to annual revision.

Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT (\$ 385.00)

Complete if Known

Application Number	
Filing Date	11/26/2003
First Named Inventor	Jonathan Sidney EDELSON
Examiner Name	
Art Unit	
Attorney Docket No.	

METHOD OF PAYMENT (check all that apply)

Check Credit card Money Order Other None

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FEE CALCULATION**1. BASIC FILING FEE**

Large Entity	Small Entity	Fee Code (\$)	Fee Code (\$)	Fee Description	Fee Paid
1001 770	2001 385	Utility filing fee	385		
1002 340	2002 170	Design filing fee			
1003 530	2003 265	Plant filing fee			
1004 770	2004 385	Reissue filing fee			
1005 160	2005 80	Provisional filing fee			
SUBTOTAL (1)		(\$ 385.00)			

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

Total Claims	Independent Claims	Multiple Dependent	Extra Claims	Fee from below	Fee Paid
14	1		-20** = 0	x 9 = 0	0
			- 3** = 0	x 43 = 0	0

Large Entity	Small Entity	Fee Code (\$)	Fee Code (\$)	Fee Description
1202 18	2202 9	Claims in excess of 20		
1201 86	2201 43	Independent claims in excess of 3		
1203 290	2203 145	Multiple dependent claim, if not paid		
1204 86	2204 43	** Reissue independent claims over original patent		
1205 18	2205 9	** Reissue claims in excess of 20 and over original patent		
SUBTOTAL (2)		(\$ 0-)		

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3. ADDITIONAL FEES**Large Entity** **Small Entity**

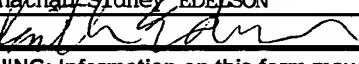
Fee Code (\$)	Fee (\$)	Fee Code (\$)	Fee (\$)	Fee Description	Fee Paid
1051 130	2051 65	Surcharge - late filing fee or oath			
1052 50	2052 25	Surcharge - late provisional filing fee or cover sheet			
1053 130	1053 130	Non-English specification			
1812 2,520	1812 2,520	For filing a request for ex parte reexamination			
1804 920*	1804 920*	Requesting publication of SIR prior to Examiner action			
1805 1,840*	1805 1,840*	Requesting publication of SIR after Examiner action			
1251 110	2251 55	Extension for reply within first month			
1252 420	2252 210	Extension for reply within second month			
1253 950	2253 475	Extension for reply within third month			
1254 1,480	2254 740	Extension for reply within fourth month			
1255 2,010	2255 1,005	Extension for reply within fifth month			
1401 330	2401 165	Notice of Appeal			
1402 330	2402 165	Filing a brief in support of an appeal			
1403 290	2403 145	Request for oral hearing			
1451 1,510	1451 1,510	Petition to institute a public use proceeding			
1452 110	2452 55	Petition to revive - unavoidable			
1453 1,330	2453 665	Petition to revive - unintentional			
1501 1,330	2501 665	Utility issue fee (or reissue)			
1502 480	2502 240	Design issue fee			
1503 640	2503 320	Plant issue fee			
1460 130	1460 130	Petitions to the Commissioner			
1807 50	1807 50	Processing fee under 37 CFR 1.17(q)			
1806 180	1806 180	Submission of Information Disclosure Stmt			
8021 40	8021 40	Recording each patent assignment per property (times number of properties)			
1809 770	2809 385	Filing a submission after final rejection (37 CFR 1.129(a))			
1810 770	2810 385	For each additional invention to be examined (37 CFR 1.129(b))			
1801 770	2801 385	Request for Continued Examination (RCE)			
1802 900	1802 900	Request for expedited examination of a design application			

Other fee (specify) _____

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$)

(Complete if applicable)

SUBMITTED BY	Name (Print/Type)	Registration No. (Attorney/Agent)	Telephone (503) 621-3286
Signature			Date 11/26/2003

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Patent Application of

Jonathan S EDELSON

for

High Phase Order Motor with Mesh Connected Windings

Cross-Reference to Related Applications

[1] This application is a division of Application No. 09/713,654 filed November 15, 2000, which claims the benefit of U.S. Provisional Application No. 60/242,622, hereby incorporated herein by reference, filed 23 October 2000.

Background of the Invention

[2] An induction motor is commonly driven by an inverter. An inverter is a device capable of supplying alternating current of variable voltage and variable frequency to the induction motor, allowing for control of machine synchronous speed and thus of machine speed. The inverter may also be used with AC induction generators, and can cause an AC induction motor to act as a generator for braking applications.

[3] In many cases, the cost of the inverter is considerably greater than the cost of the motor being supplied. It is thus necessary to minimize the size of the inverter power electronics in order to control system cost.

[4] Whereas the induction machine itself may have substantial overload capability, and may carry currents of the order of five to ten times full rated current for periods measured in minutes, the overload capability of the inverter electronics is severely limited. Exceeding the voltage or current ratings of the inverter electronics will swiftly cause device failure. Commonly, inverter electronics is specified such that it can tolerate 150% of nominal full load current for 1 minute, and for any given motor, and inverter will be selected which has the same nominal current capability as that of the motor.

[5] Voltage is set internally by the inverter system or by the rectified supply voltage. Voltage overload is normally not specified, and will cause near instantaneous destruction of semiconductor elements. The voltage ratings of the semiconductors instead set the maximum output voltage of the inverter system, and an inverter will be selected which has a maximum output voltage that matches the operating voltage of the motor at full speed.

[6] With any reasonably sized inverter, substantial motor overload capabilities remain untapped.

[7] In many traction application, there is limited available electrical power. Thus requirements for high overload capability can only be met at low speed, where high torque is required for starting, but reduced speed means that mechanical power output is still low. Such low speed torque requirements require high current to flow though the motor, but do not require high operating voltage. It is thus possible to trade high speed operating capability for low speed overload capability at the design stage of a motor drive system.

[8] By increasing the number of series turns in the motor windings, higher slot current may be achieved with the same terminal current, thus permitting the same inverter to provide greater overload current to the motor. This increase in overload capability comes at a substantial cost. The increased number of series turns means that the motor operating voltage is increased, operation at high speed is prevented. Most motors are designed for dual voltage operation, through the expedient of operating various subcircuits of the motor in series or parallel connection. The change between series and parallel connection may be accomplished though suitable contactor arrangements, permitting the motor to be operated with a higher number of series turns at low speed, and a lower number of series turns at high speed. For a simple three phase induction machine system, such a system would require at least two single-pole three-phase contactors, and would only offer a factor of 1.7 increase in low speed overload capability. With three contactors, a factor of two change is possible.

[9] The change in series turns may be considered a change in induction machine impedance, or current versus voltage relation. Normally, an induction machine will have a fixed relationship between synchronous speed and impedance, characterized by the Volts/Hertz ratio. For a given inverter and machine frame, a machine wound with a higher Volts/Hertz ratio will have a lower maximum speed, but higher peak low speed torque.

[10] It is thus necessary to provide for an induction machine drive system in which the induction machine presents a variable Volts/Hertz ratio to the inverter. For high speed operation, the Volts/Hertz ratio would be adjusted to a low value, in order to maintain a suitable induction machine operational voltage. For low speed operation, the Volts/Hertz ratio would be adjusted to a higher value, so as to permit high overload torque operation.

Brief Summary of the Invention

[11] From the foregoing it will be appreciated that a serious need exists for a motor drive system that has variable impedance. The present invention provides a drive system that can achieve high torque overload at low speeds whilst also being capable of providing sufficient voltage for high speed applications. In the present invention a high phase order induction machine is used with each phase terminal separately connected to an inverter output. The windings of the induction machine are wound as full span connected windings, and the motor terminals are connected with a mesh connection to produce a low impedance output. The inverter is capable of operating with a variable phase sequence that changes the effective impedance of the motor.

[12] A technical advantage of the present invention is that impedance may be electronically varied. This eliminates the need and cost of mechanical contactor arrangements and allows greater variability in impedance.

[13] A further technical advantage is that a motor may achieve substantially high torque at low speeds, whilst also being able to operate at high speeds.

[14] A yet further technical advantage is that an inverter output may be better exploited by a motor.

[15] Further technical advantages will become apparent from a consideration of the figures and the ensuing descriptions.

Brief Description of the Several Views of the Drawing

[16] For a more complete explanation of the present invention and the technical advantages thereof, reference is now made to the following description and the accompanying drawings, in which:

[17] **Figure 1** illustrates how the winding terminals of a polyphase motor may be connected to a polyphase inverter.

[18] **Figures 2A-2E** illustrate a plurality of ways in which the polyphase inverter may be connected to a polyphase motor.

[19] **Figures 3A-3D** illustrate how winding terminals of a motor connected to a polyphase inverter in a particular fashion may be driven by the inverter with various phase angles.

Detailed Description of the Invention

[20] In the method and apparatus of the present invention, a high phase order induction motor is connected to a high phase count inverter. Rather than using a star connection for the high phase count machine, the motor is connected mesh, meaning that the two winding terminals of each motor phase are each connected to separate inverter output terminals, whilst each inverter output terminal is connected to two motor phase terminals. The three phase mesh connection is well known in the art, and is commonly known as a delta connection.

[21] In an induction machine, each phase winding set can be described by two terminals. There may be a larger number of terminals, but these are always grouped in series or parallel groups, and the entire set can be characterized by two terminals. In a star connected machine, one of these terminals is driven by the inverter or power supply, while the other terminal is connected to the machine neutral point. All current flows through one terminal, through the neutral point into other windings, and though the driven terminals of the other phases. In a mesh connected machine, these two terminals are connected directly to two different supply points. An example of how this may be done is shown in **Fig 1**, in which the stator slots 4 are shown as straight lines running down the inside of the stator, and inverter terminals 2, are shown as circles, alongside which is marked phase angles of each of the inverter terminals. Electrical connections 3 between the winding terminals in stator slots 4 and inverter terminals 2 are represented by dashed lines. Two winding halves are displayed opposite one another, and are actually joined to one another, although this is not shown. The configuration describes a 9 phase machine connected with an $S=3$ connection - identical to **Fig 2e**.

[22] In contrast to three phase systems, in which there are only three inverter terminals and six motor windings terminals, in a high phase count system with N phases, there are N inverter terminals and $2N$ motor windings terminals. There are thus a substantial number of choices for how an N phase system may be mesh connected. This set of choices is greatly reduced by rotational symmetry requirements, specifically each winding must be connected to two inverter terminals with the same electrical angle difference between them as for every other winding.

[23] A simple graphical schematic of the permissible inverter to motor windings connections may thus be described for a polyphase motor having N phases. In the following embodiment, N is equal to 9, but it is to be understood that this limitation is made to better illustrate the invention; other values for N are also considered to be within the scope of the present invention. **Fig. 2a** shows 9 evenly

spaced terminals 4 and a center terminal 6. Each of the terminals 4 represent one end of a motor winding 1 and the center terminal 6 represents the other end of the motor winding. An inverter 5 has 9 terminals 2, which are connected to one of the terminals 4 of each of the motor windings 1 via electrical connectors 3 as shown.

[24] Permissible connections of the 9 phase windings are either from the center point, to each of the 9 points on the circle (this being the star connection shown as **Fig. 2a**) or from each of the 9 points to another point S skipped points distant in the clockwise direction, where S represents the number of skipped points (inverter terminals). This latter is shown in **Figs. 2b-e**; in **Fig. 2b** motor winding 1 is represented by a line, and in **Figs. 2c-e** inverter 5 and electrical connectors 3 have been omitted for the sake of clarity. It will be noted that for each S from 0 to 3 there is a corresponding S from 4 to 7 that produces a mirror image connection.

[25] **Fig. 2** shows all permissible connections for a 9 phase system from S=0 to S=4 as well as the star connection. Noted on the star connection diagram (**Fig. 2a**) are the relative phase angles of the inverter phases driving each terminal. For a given inverter output voltage, measured between an output terminal 2 and the neutral point, 6 each of these possible connections will place a different voltage on the connected windings. For the star connection, the voltage across the connected windings is exactly equal to the inverter output voltage. However, for each of the other connections (**Figs. 2b-e**), the voltage across a winding is given by the vector difference in voltage of the two inverter output terminals 2 to which the winding 1 is connected. When this phase difference is large, then the voltage across the winding will be large, and when this phase difference is small, then the voltage across the winding will be small. It should be noted that the inverter output voltage stays exactly the same in all these cases, just that the voltage difference across a given winding will change with different connection spans. The equation for the voltage across a winding is given by:
$$2 * \sin((\text{phasediff})/2) * V_{\text{out}}$$
 where phasediff is the phase angle difference of the inverter output terminals driving the winding, and V is the output to neutral voltage of the inverter.

[26] Thus, referring to **Fig. 2**, when S=0, the phase angle difference is 40 degrees, and the voltage across a winding is $0.684V_{\text{out}}$. When S=1 (**Fig. 2c**), the phase angle difference is 80 degrees, and the voltage across the winding is $1.29V_{\text{out}}$. When S=2 (**Fig. 2d**), the phase angle difference is 120 degrees, and the voltage across the winding is $1.73V_{\text{out}}$. Finally, when S=3 (**Fig. 2e**), the phase angle difference is 160 degrees, and the voltage across the winding is $1.97V_{\text{out}}$. For the same inverter output voltage, different connections place different

voltage across the windings, and will cause different currents to flow in the windings. The different mesh connections cause the motor to present a different impedance to the inverter.

[27] As disclosed above, in an induction machine, each motor winding set can be described by two terminals. There may be a larger number of terminals, but these are always grouped in series or parallel groups, and the entire set can be characterized by two terminals. Thus whilst Fig. 2 discloses a single motor winding 1 connected to terminals 4 and 6, it is to be understood that this limitation is made to better illustrate the invention; multiple phase windings connected between the terminals are also considered to be within the scope of the present invention.

[28] To deliver the same power to the motor, the same voltage would have to be placed across the windings, and the same current would flow through the windings. However, for the S=0 connection, to place the same voltage across the windings, the inverter output voltage would need to be much greater than with the S=3 connection. If the inverter is operating with a higher output voltage, then to deliver the same output power it will also operate at a lower output current. This means that the S=0 connection is a relatively higher voltage and lower current connection, whereas the S=3 connection is a relatively lower voltage, higher current connection.

[29] The S=0 connection is desirable for low speed operation, where it increases the overload capabilities of the drive, and permits much higher current to flow in the motor windings than flow out of the inverter terminals. The S=3 connection is desirable for high speed operation, and permits a much higher voltage to be placed across the windings than the inverter phase to neutral voltage. This change in connection is quite analogous to the change between star and delta connection for a three phase machine, and may be accomplished with contactor apparatus. However the number of terminals renders the use of contactors to change machine connectivity essentially impracticable.

[30] There is, however, an additional approach available with high phase order inverter driven systems.

[31] The inverter, in addition to being an arbitrary voltage and current source, is also a source of arbitrary phase AC power, and this output phase is electronically adjustable. Any periodic waveform, including an alternating current may be described in terms of amplitude, frequency, and phase; phase is a measure of the displacement in time of a waveform. In a polyphase inverter system, phase is measured as a relative phase displacement between the various outputs, and between any pair of inverter terminals, an electrical phase angle may be

determined. In the case of conventional three phase systems, this electrical phase angle is fixed at 120 degrees. However in polyphase systems this phase angle is not fixed. Thus, while the machine terminals 1..9 may be fixed in their connection to inverter terminals 1..9, the phase relation of the inverter terminals connected to any given motor winding terminals is not fixed. By changing the inverter phase relation, the impedance that the motor presents to the inverter may be changed. This may be done without contactors.

[32] With Reference to Fig. 3, a 9 phase machine is connected to the inverter system using the $S=3$ mesh. One terminal of each of two windings 1 is connected to each inverter terminal 2. When driven with 'first order' phase differences, then the results are as described above for the $S=3$ mesh. However, if the phase angles are adjusted by multiplying each absolute phase reference by a factor of three, then the phase differences placed across each winding become the same as those found in the $S=2$ case, although the topological connectivity is different. If the phase angles are adjusted by a multiplicative factor of five, then the voltages across windings become like those of the $S=1$ case, and with a multiplicative factor of seven, the voltages become like those of the $S=0$ case. A multiplicative factor of nine causes all phases to have the same phase angle, and places no voltage difference across the winding.

[33] These changes in phase angle are precisely the changes in phase angle used to change the operating pole count of a high phase order induction machine, as described in others of my patent applications and issued patents.

[34] If a high phase count concentrated winding induction machine is operated by an inverter, but is connected using a mesh connection, then changes in pole count of the machine will be associated with changes in machine effective connectivity. These changes in effective connectivity permit high current overload operation at low speed, while maintaining high speed capability, without the need for contactors or actual machine connection changes.

[35] Of particular value are machines connected such that the fundamental, or lowest pole count, operation is associated with a relative phase angle across any given winding of nearly, but not exactly, 120 degrees. In these cases, altering the output of the inverter by changing the absolute phase angles by a multiplicative factor of three, which may also be described as operation with the third harmonic will result in the relative phase angle across any given winding becoming very small, and causing large winding currents to flow with low inverter currents. A particular example would be a 34 slot, 17 phase machine, wound with full span, concentrated windings, to produce a two pole rotating field. The winding terminations are connected to the inverter using the $S=5$ mesh. The

relative phase angle of the inverter outputs placed across any given winding would be 127 degrees, and the voltage placed across this winding relative to the inverter output voltage is 1.79 times the inverter output voltage. If the machine is then operated with a third harmonic waveform, it will operate as a six pole machine. The relative phase angle across any given winding is now $127*3 \bmod 360 = 21$ degrees, and the voltage placed across the winding relative to the inverter output voltage is 0.37 times the inverter output voltage. Simply by changing the inverter drive angles, the Volts/Hertz relationship of the motor is increased, and inverter limited overload capability is enhanced.

[36] To determine the ideal S , the number of skipped inverter terminals between the winding terminals of each phase of the motor, which would result in the greatest change of impedance when the inverter drives the motor with substantial third harmonic, one would use the formula $(N/3)-1$, rounded to the nearest integer, for values of N (number of phases in motor) not divisible by 3. When N is divisible by 3, one would use the formula $N/3$ to determine the skip number.

[37] Other connectivity is certainly possible. The connection described above will tend to maximize machine impedance for the third harmonic, but will actually decrease machine impedance for fifth harmonic. A connection that most closely approximates full bridge connection, e.g. the $S=7$ connection for the 17 phase machine described above, will show gradually increasing machine impedance for the 3rd, 5th, 7th, 9th, 11th, 13th, and 15th harmonics. This may be of particular benefit, for example, with machines operated with square wave drive. Operation with high pole counts is not generally considered preferable, however it may be of benefit in the particularly desirable case of operating at high overload and low speed. The number of slots is not restricted, nor are the number of phases or poles. In order to determine the value of S (skip number) in the winding to inverter connections, one may use the formula $(N-3)/2$, when N (number of motor phases) is an odd number. When N is even by may be divided into subsets of odd phase counts, the formula may similarly be used for the odd subsets.

[38] The general principal of the present invention may be utilized for the operation of high phase order induction machines including motors, generators, and motor/generators, and may also be utilized for different loads which require variable frequency supply, e.g. induction heating applications. Also, saturation of single harmonics are not required, and an exceedingly variable impedance may be produced by the gradual and increasing superimposition of harmonic content, for example, of the third harmonic.

[39] The present invention has been described with regard to rotary induction motors, however it may be implemented with linear induction motors too, using similar techniques for changing winding impedance. Where the windings of a linear or also of a rotary induction motor comprise single inductors instead of coils, then inverter output phase angle may be altered by an even multiplicative factor in order to effect impedance changes. In some cases, the inverter may even multiply each phase angle by a fractional factor to vary the impedance of the motor.

[40] The present invention has been described as a way of connecting a polyphase motor to a polyphase inverter. Furthermore, there have been described methods of electrically varying the impedance, and methods to design the windings to inverter connections in order to optimize such impedance variation. In this way, the same motor may act as though it has a high number of series turns for low speed operation, being supplied with high voltage and low current, yet still be able to reach high speeds as though the motor has relatively few series turns. Also, contactor arrangements are not essential. However, an additional facet of the present invention provides for a plurality of inverter to windings connections to be set up in the same machine, e.g. in 9 phase machine, S=0 and S=3 could both be independently connected or available to be connected. Contactors or switches would be arranged in each terminal to change the way the windings are connected to the inverter terminals based on the dual arrangements set up in the machine. This is an example of another way in which the motor impedance may be controlled according to the present invention.

[41] The word "terminal" has been used in this specification to include any electrically connected points in the system - this may be a screw, for example, or any electrical equivalent, for example, it may simply comprise a wire connecting two components in a circuit.

[42] In a similar sense, inverter output elements are commonly half bridges, but they may alternatively comprise other switching elements. One embodiment of the present specification has described two winding terminals connected to a single inverter terminal. The single inverter terminal referred to is intended to also include electrical equivalents, such as a device made of two inverter terminals that are electrically connected together.

[43] Thus, it is apparent that there has been provided, in accordance with the present invention, a method and apparatus for a high phase order motor with mesh connected windings that satisfies the advantages set forth above. Thus, the mesh connection and the implementation techniques of the present invention may be used in virtually all motor applications.

[44] While this invention has been described with reference to numerous embodiments, it is to be understood that this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments will be apparent to persons skilled in the art upon reference to this description. It is to be further understood, therefore, that numerous changes in the details of the embodiments of the present invention and additional embodiments of the present invention will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description. It is contemplated that all such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.

[45] All publications and patent applications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

Claims

1. A method for varying the impedance of a motor having N phases, where N is greater than three, comprising:
 - a) synthesizing a plurality of phases of alternating current output using an inverter system, and connecting each phase electrically to at least one inverter terminal;
 - a) connecting, electrically, each phase of said motor to:
 - (i) a first terminal of said inverter;
 - (ii) a second terminal of said inverter S skipped terminals distant from said first terminal in order of electrical phase angle, where S is the skip number and represents the number of skipped terminals; so that a phase angle difference between the two inverter terminals to which each motor phase is connected is identical for each motor phase;
 - c) varying the phase angle difference between said first terminal and said second terminal.
2. The method of claim 1 further comprising the step of
 - a) receiving a signal indicating a requirement to vary the impedance of the motor,and wherein said step of varying the phase angle difference comprises varying the phase angle difference substantially in accordance with said requirement to vary the impedance of the motor.
3. The method of claim 1 wherein said step of varying the phase angle difference comprises: decreasing the phase angle difference between said first terminal and said second terminal to increase the impedance of the motor.
4. The method of claim 1 wherein said step of varying the phase angle difference comprises: increasing the phase angle difference between said first terminal and said second terminal to decrease the impedance of the motor.
5. The method of claim 1 wherein N is an odd number, and wherein said step of varying the phase angle difference between said first terminal and said second terminal comprises switching a drive waveform of said inverter from a fundamental frequency output to a harmonic thereof.

6. The method of claim 1 wherein N is an odd number, and wherein said step of varying the phase angle difference between said first terminal and said second terminal comprises superimposing upon a primary drive waveform of said inverter, one or more harmonics thereof, to a required degree of superimposition.
7. The method of claim 1 wherein N is a multiple of 3, and wherein the skip number is $N/3$, and wherein said step of varying the phase angle difference comprises multiplying each of the phase angles by 3 to decrease the impedance of the motor.
8. The method of claim 1 wherein N is a multiple of 3, and wherein the skip number is $N/3$, and wherein said step of varying the phase angle difference comprises dividing each of the phase angles by 3 to increase the impedance of the motor.
9. The method of claim 1 wherein N is not a multiple of 3, and wherein the skip number is $(N/3)-1$ rounded to the nearest integer, and wherein said step of varying the phase angle difference comprises multiplying each of the phase angles by 3 to decrease the impedance of the motor.
10. The method of claim 1 wherein N is not a multiple of 3, and wherein the skip number is $(N/3)-1$ rounded to the nearest integer, and wherein said step of varying the phase angle difference comprises dividing each of the phase angles by 3 to increase the impedance of the motor.
11. The method of claim 1 wherein the step of varying the phase angle difference comprises the step of providing increasing proportions of one or more odd order harmonics.
12. The method of claim 1 wherein a phase angle difference between said first terminal and said second terminal is approximately 120 degrees, and wherein said step varying the phase angle difference comprises adding a third harmonic component to a primary drive waveform of the inverter.
13. The method of claim 12 wherein said step of adding a third harmonic component is done gradually.

14. The method of claim 1 wherein said steps of connecting the motor to a first terminal and connecting said motor to a second terminal is done to achieve the largest phase angle difference possible between the two terminals of each winding.

Abstract of the Disclosure

[46] A high phase order induction machine drive system is disclosed. This has an inverter system for the synthesis of a plurality of phases of alternating current output, and a N-phase induction motor (N is greater than 3). The motor is connected to the inverter terminals so that each motor phase is electrically connected to a first inverter terminal and a second inverter terminal $S + 1$ inverter terminals distant from the first inverter terminal in order of electrical phase angle (S is the skip number). The phase angle difference between the pair of inverter terminals to which each motor phase is connected is identical for each motor phase.

Figure 1

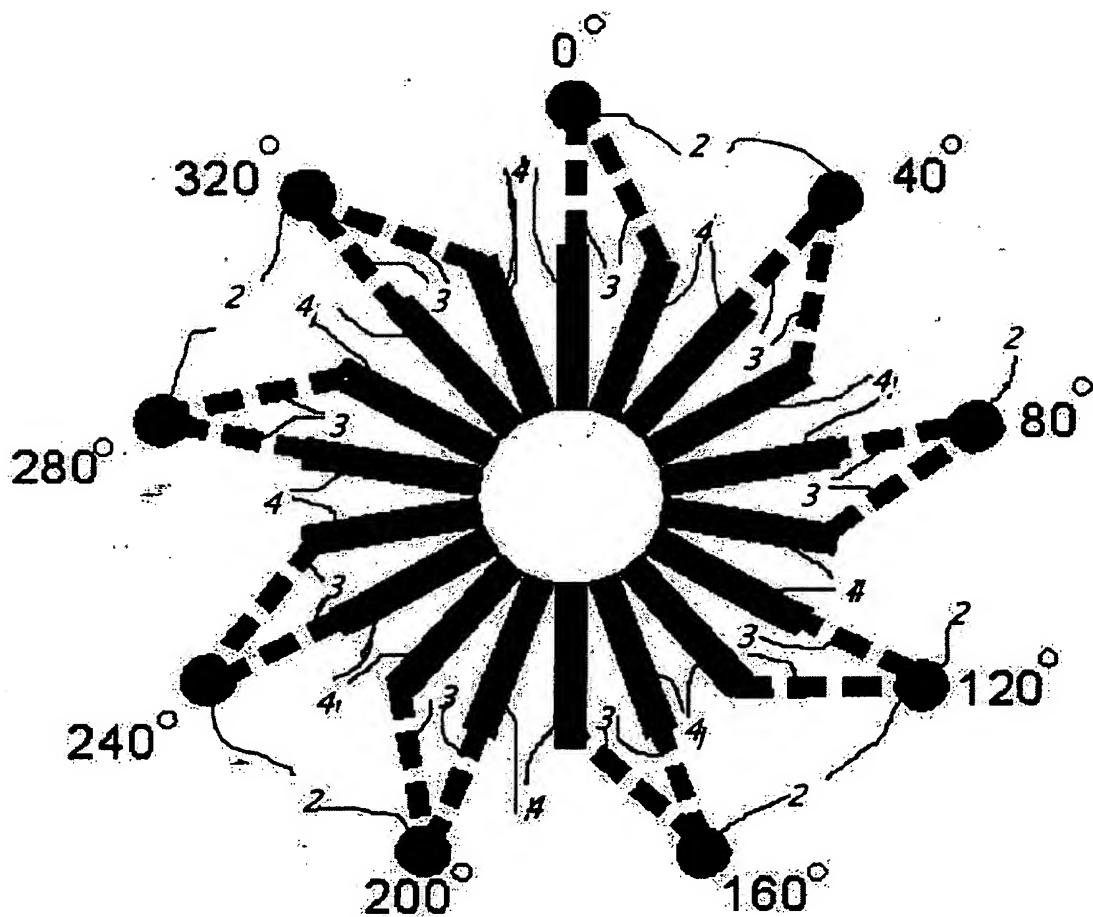


Figure 2A

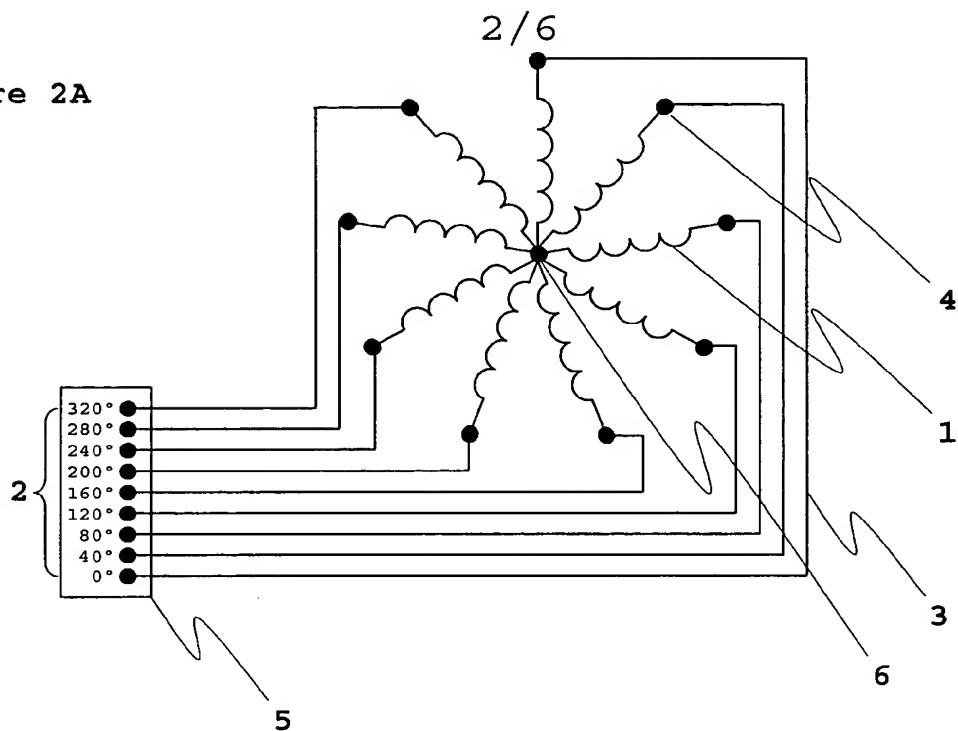
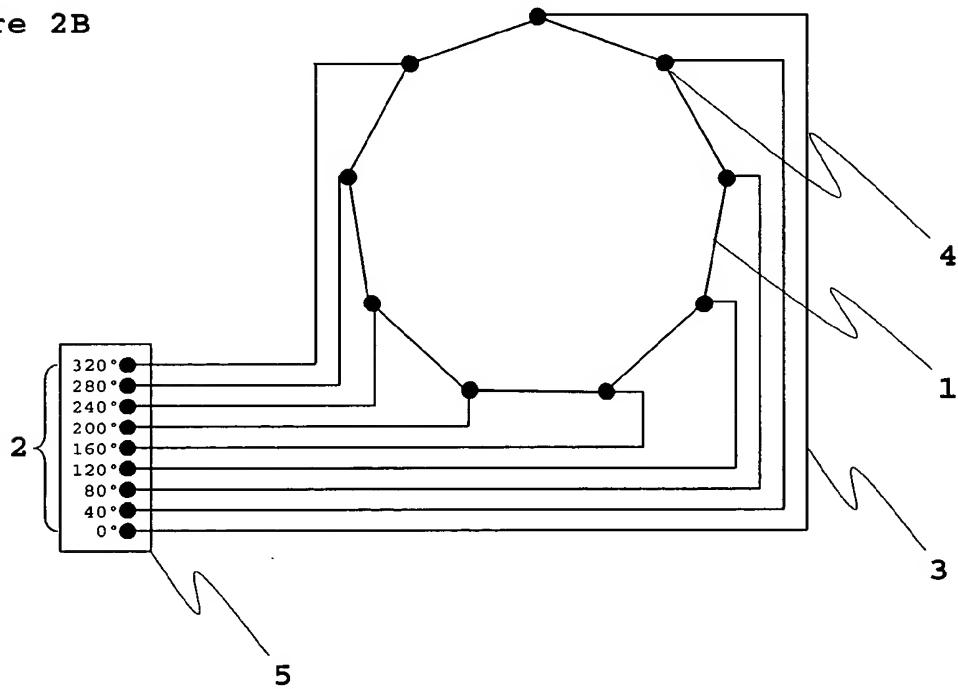


Figure 2B





3 / 6

Figure 2C

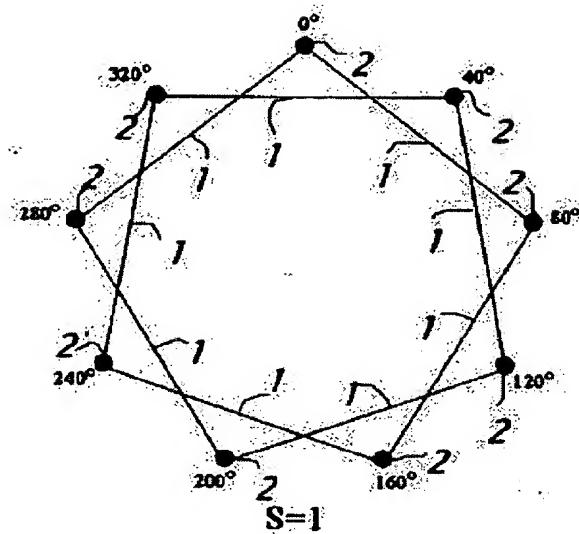


Figure 2D

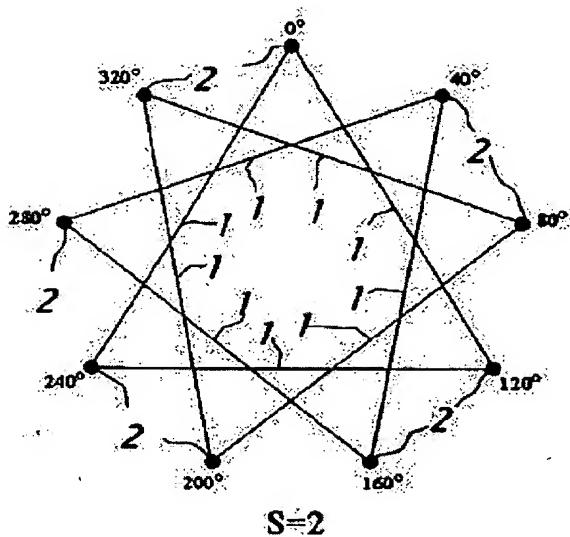
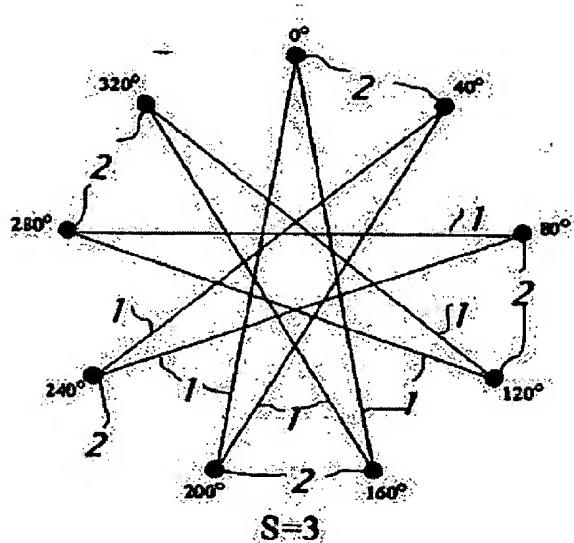




Figure 2E



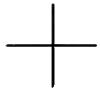
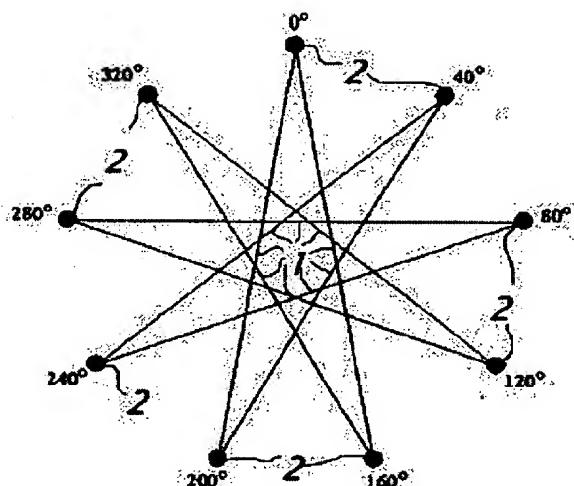
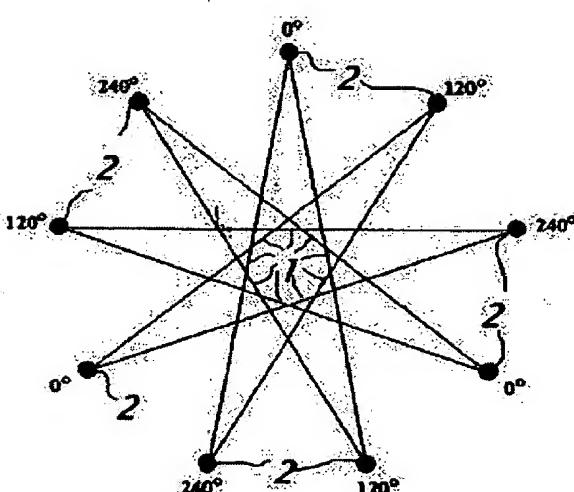


Figure 3A



Fundamental

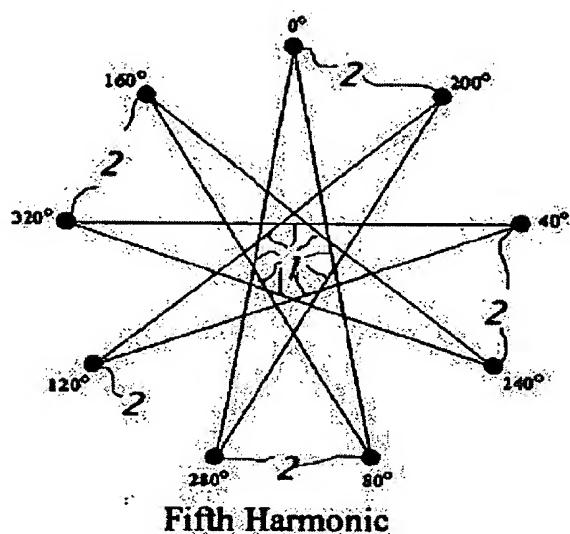
Figure 3B



Third Harmonic

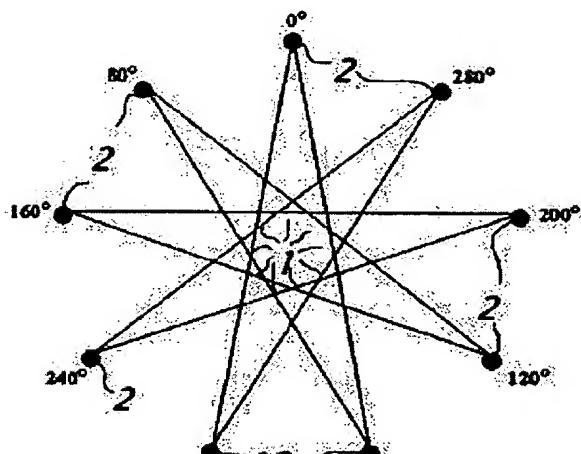


Figure 3C



Fifth Harmonic

Figure 3D



Seventh Harmonic



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Attorney Docket Number	
First Named Inventor	Jonathan Sidney EDELSON
COMPLETE IF KNOWN	
Application Number	
Filing Date	11/26/2003
Art Unit	
Examiner Name	

I hereby declare that:

Each inventor's residence, mailing address, and citizenship are as stated below next to their name.

I believe the inventor(s) named below to be the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

High Phase Order Motor with Mesh Connected Windings

(Title of the Invention)

the specification of which

 is attached hereto**OR** was filed on (MM/DD/YYYY) as United States Application Number or PCT InternationalApplication Number and was amended on (MM/DD/YYYY) (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

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[Page 1 of 2]

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+1.503.621.3286

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NAME OF SOLE OR FIRST INVENTOR:

A petition has been filed for this unsigned inventor

Given Name

(first and middle [if any])

Jonathan Sideny

Family Name

or Surname

EDELSON

Inventor's
Signature

Date

11/26/2003

Residence: City

Somerville

State

MA

Country

US

Citizenship

US

Mailing Address

23545 NW Skyline Blvd

City

North Plains

State

OR

ZIP

97133-9204

Country

US

NAME OF SECOND INVENTOR:

A petition has been filed for this unsigned inventor

Given Name

(first and middle [if any])

Family Name

or Surname

Inventor's
Signature

Date

Residence: City

State

Country

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Additional inventors or a legal representative are being named on the _____ supplemental sheet(s) PTO/SB/02A or 02LR attached hereto.